METHOD FOR PROVIDING ERROR INFORMATION RELATING TO INCONSISTENCIES IN A SYSTEM OF DIFFERENTIAL EQUATIONS

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Cross-Reference to Related Application:

This application is a continuation of copending International Application No. PCT/DE02/01878, filed May 23, 2002, which designated the United States and which was not published in

10   English.

Background of the Invention:

Field of the Invention:

The invention relates to a method for providing error

15   information relating to inconsistencies in a system of differential equations.

It is known in the prior art to describe a technical system with systems of differential equations. With the assistance of

20   numerical methods using a computer system, or of an analog computer, it is possible to simulate the systems by calculating solutions to the systems of differential equations for specific initial or boundary conditions. Examples for the description of technical systems and typical simulation

25   methods can be taken from standard works of the relevant field of specialization. Detailed instructions therefor are

specified, for example, in G. Schmidt, "Grundlagen der Regelungstechnik" ["Principles of Control Engineering"], 2nd edition, Springer, Berlin, 1987, in Unbehauen, "Regelungstechnik I" ["Control Engineering I"], 6th edition,

5 Friedr. Viehweg & Sohn, Braunschweig/Wiesbaden, 1989, in Unbehauen, "Regelungstechnik II" ["Control Engineering II"], 5th edition, Friedr. Viehweg & Sohn, Braunschweig/ Wiesbaden, 1989, in Unbehauen, "Regelungstechnik III" ["Control Engineering III"], 2nd edition, Friedr. Viehweg & Sohn,

10 Braunschweig/Wiesbaden, 1986, in E. Pfeiffer, "Einführung in die Dynamik" ["Introduction to Dynamics"], B.G. Teubner, Stuttgart, 1989, and in E. Ziegler (ed.), "Teubner-Taschenbuch der Mathematik" ["Teubner Manual of Mathematics"] B.G. Teubner, Stuttgart, 1996. When simulating, the problem

15 frequently arises that a method for numerically solving a system of differential equations will terminate because the fundamental system of differential equations is singular. For the same reason, it can happen that an analog computer cannot foresee the system behavior. In addition, it frequently

20 happens that solutions that are not plausible occur when solving the systems of differential equations.

In such a case, it is known in the prior art that the programmer or a user of a program for solving differential

25 equations is responsible for locating errors. With extensive experience, it is possible to locate the causes of the

singularity and, if appropriate, to reduce errors in the modeling of the technical system. This is generally very time consuming and costly.

5   A method for automatic structure analysis of very large systems of differential-algebraic equations is described in S. Chowdry et al: "Automatic structure analysis of large scale differential algebraic systems" IMTC 2001. Proceedings of the 18th IEEE Instrumentation and Measurement Technology

10   Conference, Budapest, Hungary, May 21-23, 2001, IEEE Instrumentation and Measurement Technology Conference (IMTC): New York, NY: IEEE, US, Vol. 1 of 3, Conf. 18, May 21, 2001 (2001-05-21), pages 798-803. This method takes account both of numerical and of symbolic information, and also incorporates

15   the effects of linear terms rigorously into the mathematical system, and is capable of providing a very accurate representation of the structure of a system of differential-algebraic equations.

20   A structural algorithm that takes account of the structural properties of systems of differential-algebraic equations is described in the scientific article by J. Unger et al: "Structural analysis of differential-algebraic equation systems - theory and applications" Comput. Chem. Eng.;

25   Computers & Chemical Engineering Aug 1995, Pergamon Press Inc., Tarrytown, NY, USA, Vol. 19, No. 8, August 1995 (1995-

08), pages 867-882. In that case, two systematically different structural approaches are implemented on a computer system in order to analyze systems of differential-algebraic equations structurally. These computer programs are applied both as

5   separate programs for supporting the development of simulation models with a low index, and as constituents of the DIVA simulation environment, in order to facilitate a selection of suitable numerical algorithms, and to calculate consistent initial conditions.

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The fact that the structural index of a linear differential-algebraic equation with constant coefficients and with the index 1 can be arbitrarily high and to that extent contradicts a result previously published in the literature is shown by the

15   scientific publication by Gunter Reissig et al: "Differential-algebraic equations of index 1 may have an arbitrarily high structural index" Siam J. SCI. Comput.; Siam Journal of Scientific Computing 2000 SOC for Industrial & Applied Mathematics Publ., Philadelphia, PA, USA, Vol. 21, No. 6, 2000,

20   pages 1987-1990. This publication further states that when applied to differential-algebraic equations with an index of 1, Pantelides' algorithm can execute an arbitrarily high number of iterations and differentiations.

Summary of the Invention:

It is accordingly an object of the invention to provide a method for providing error information relating to inconsistencies in a system of differential equations which overcomes the above-mentioned disadvantages of the heretofore-known devices and methods of this general type.

With the foregoing and other objects in view there is provided, in accordance with the invention, a method for predicting the behavior of a technical system starting from prescribed system properties, boundary conditions, and/or starting from prescribed influences on the system. The method comprises the following steps:

providing a computer system;

defining a system of equations describing the technical system, the equations having the form $\underline{f}\left(t,\underline{x}(t),\underline{\dot{x}}(t),...,\underline{x}^{(k)}(t),\underline{p}\right)=\underline{0}$, and including:

$$f_1\left(t,\underline{x}(t),\underline{\dot{x}}(t),...\underline{x}^{(k)}(t),\underline{p}\right)=0,$$

$$f_2\left(t,\underline{x}(t),\underline{\dot{x}}(t),...\underline{x}^{(k)}(t),\underline{p}\right)\approx 0,$$

$$\vdots$$

$$f_n\left(t,\underline{x}(t),\underline{\dot{x}}(t),...\underline{x}^{(k)}(t),\underline{p}\right)=0,$$

wherein $\underline{x}$(t) and derivatives $\underline{\dot{x}}(t),...,\underline{x}^{(k)}$ thereof in each case

have *m* elements, and $\underline{p}$ is a parameter vector that can occur in

the system of equations; and

executing a test method for providing error information

5   relating to inconsistencies in the system of equations on the

computer system, the test method having the following steps 1

to 3:

step 1: setting up a dependence matrix $\underline{\underline{A}}$ with *m* columns and *n*

rows, and setting an element $\underline{A}$ to

10   $\underline{A}(i,j) \neq 0$ when an ith row of $\underline{f}$ defined with $\underline{f}_i\left(t,\underline{x}(t),\underline{\dot{x}}(t),...,\underline{x}^{(k)}(t),\right)$ is

a function of

   a) a jth element of $\underline{x}$ expressed as $\underline{x}_j$(t); or

   b) one of the derivatives of the jth element of $\underline{x}$ defined

   as $\underline{x}_j^{(s)}$(t);

15   and otherwise setting the element $\underline{\underline{A}}(i, j) = 0$;

step 2: determining a set of row ranks each having the numbers

of those rows of the dependence matrix $\underline{\underline{A}}$ that are mutually

dependent and determining a set of column ranks of the

dependence matrix $\underline{\underline{A}}$ each having the numbers of those columns

of the dependence matrix $\underline{\underline{A}}$ that are mutually dependent if such row ranks and/or column ranks are present; and

step 3: outputting error information containing the numbers contained in each row rank determined in step 2 and in each
5   column rank determined in step 2.

The invention is based on the idea of examining the system of differential equations for inconsistencies with the aid of combinatorial methods as early as before a simulation, that is
10   to say before executing numerical calculating steps or building an analog computer. When information relating to such inconsistencies is at hand, it is possible to deduce errors in the modeling of the technical system, or errors in the technical system itself, that can cause undesired
15   contamination in a later simulation step, or even render the system incapable of being simulated. There is no need for a time-consuming execution of the simulation as far as termination, nor for a trial simulation. The correction of the model of the technical system or of the technical system
20   itself is substantially facilitated by the presence of information relating to inconsistencies.

The first step, of the method according to the invention, provides for setting up a dependence matrix $\underline{\underline{A}}$. The dependence
25   matrix $\underline{\underline{A}}$ has exactly as many columns as the dimension of the solution vector $\underline{x}$ of the system of differential equations. The

dependence matrix $\underline{A}$ has exactly as many rows as the number of differential equations in the given system of differential equations.

5   The invention is not limited in this case only to systems of differential equations of the form $\underline{f}\left(t, \underline{x}(t), \underline{\dot{x}}(t), \ldots, \underline{x}^{(k)}(t), \underline{p}\right) = \underline{0}$. It can also be applied to special cases in which the system of equations for simulating the technical system has the form, for example, of $\underline{f}(t, \underline{x}(t)) = \underline{0}$. In such a case, the talk is not of

10 a system of differential equations but of a generally nonlinear system of equations.

Moreover, it is not absolutely necessary for the system of differential equations that is provided for the simulation to

15 be examined itself for inconsistencies. Moreover, another system of differential equations that describes the same technical system or the same technical process can be examined for inconsistencies. This can be advantageous when the last-named system of differential equations has a simpler structure

20 than that to be simulated later. For example, in the simulation of electric networks the equations of modified node voltage analysis are usually the basis of the numerical simulation, although the so-called branch voltage-branch current equations have a substantially simpler structure. It

25 is even possible frequently to determine more inconsistencies

or to limit inconsistencies more severely by examining systems
of differential equations with a simple structure.

The dependence matrix $\underline{\underline{A}}$ in this case has elements $\underline{\underline{A}}(i,j)$ that

5 are set either to the value "zero" or to the value "nonzero",
without regard to the absolute values of the elements of $\underline{\underline{A}}$. In
this case, the element $\underline{\underline{A}}(i,j)$ can be set to a value $\neq 0$ when the
i^{th} row of $\underline{f}$ is a function of the jth element of $\underline{x}$, or of one
of the derivatives of the jth element of $\underline{x}$. In all other

10 cases, the element $\underline{\underline{A}}(i,j)$ is set to the value "0".

It is immaterial for the method according to the invention
whether the dependence matrix $\underline{A}$ is actually set up explicitly.
Rather, what is important is the corresponding information as

15 to whether the ith row of $\underline{f}$ is a function of the ith element of
$\underline{x}$ or of one of its derivatives, or not, being available in the
following method steps.

In the second step of the method according to the invention, a

20 set of row ranks is determined that in each case have the
numbers of those rows of the dependence matrix $\underline{\underline{A}}$ or those rows
of the system of differential equations that are mutually
dependent. Moreover, a set of column ranks of the dependence
matrix $\underline{A}$ is determined that in each case have the numbers of

those columns of the dependence matrix $\underline{\underline{A}}$ or those components

of $\underline{x}$ or one of its derivatives that are mutually dependent.

Here, "row rank" is understood as follows. A set C_z of natural

5   numbers i, $1 \le i \le n$, is a row rank of a matrix with n rows and m

columns when it fulfils the following conditions:

(i)   there is no transversal T of the matrix $\underline{\underline{A}}$ such that C_z

is contained in the set of row indices of T.

10

(ii)   for each element c of C_z there is a transversal T of $\underline{\underline{A}}$

such that $C_z \backslash \{c\}$ is wholly contained in the set of the

row indices of T.

15   Here, the expression $C_z \backslash \{c\}$ represents that set which results

when the element c is removed from the set C_z.

A transversal T of the matrix $\underline{\underline{A}}$ is understood as follows. A

transversal of a matrix $\underline{\underline{A}}$ with n rows and m columns is one of,

20   if appropriate, a plurality of possible sets of positions (i,

j) of non-vanishing matrix entries $\underline{\underline{A}}$ (i, j), of which no two or

more are in the same row or column. A set T of pairs (i, j),

$1 \le i \le n, 1 \le j \le m$, constitutes a transversal of the matrix $\underline{\underline{A}}$ if T

fulfils the following conditions:

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(i) $\underline{\underline{A}}$ (i, j) does not vanish for all elements (i, j) of T,
and

(ii)   given that (i, j) and (i', j') are two different

elements of T, that is to say $i \neq i'$ or $j \neq j'$, it holds

5   that $i \neq i'$ and at the same time $j \neq j'$.

It is of less importance for the invention in this case

whether one of the possible transversals of the dependence

matrix $\underline{\underline{A}}$ is calculated. The definition of the term

10   "transversal" is required here, in order to illustrate the

terms "row rank" and "column rank".

The term "row index of the transversal T" is understood as

follows. The set Z of the "row indices of the transversal T"

15   has as elements the row indices of the elements of T. In other

words, this means that the set Z contains precisely those

numbers i for which there is a j such that the element (i, j)

is an element of T.

20   A column rank is understood as a set C_s of natural numbers i,

$1 \leq i \leq m$, of a matrix $\underline{\underline{A}}$ with n rows and m columns when it fulfils

the following conditions:

(i)   there is no transversal T of the matrix $\underline{\underline{A}}$ such that C_s

25   is contained in the set of column indices of T.

(ii)   for each element c of C_s there is a transversal T of

the matrix $\underline{\underline{A}}$ such that $C_s \backslash \{c\}$ is wholly contained in

the set of the column indices of T.

5   The "set of column indices of the transversal T" is understood

as a set Z that contains as elements the column indices of the

elements of the transversal T of the matrix $\underline{\underline{A}}$. In other words,

this means that the set Z contains precisely those numbers j

for which there is an i such that the element (i, j) is an

10   element of the transversal T of the matrix $\underline{\underline{A}}$.

After step 2 according to the invention is carried out, there

is present a set of row ranks that respectively have the

numbers of those rows of the dependence matrix $\underline{\underline{A}}$ or those rows

15   of the system of differential equations that are mutually

dependent. Moreover, a set of column ranks of the dependence

matrix $\underline{\underline{A}}$ is present that in each case have the numbers of

those columns of the dependence matrix $\underline{\underline{A}}$ or of those

components of $\underline{x}$ or one of its derivatives that are mutually

20   dependent.

It is particularly easy having this information to deduce

structural errors of the system of differential equations that

is present as starting point. Such structural errors or

25   inconsistencies in the original system of differential

equations are frequently causes of errors in the calculation of the solution of the system of differential equations.

A basic step in executing the method according to the invention
5   consists in finding row ranks and column ranks. Methods for finding row ranks and column ranks are known. Methods for determining "row ranks" are to be found in the literature under the keyword of "minimally structurally singular subsets of equations" (compare C.C. Pantelides, The consistent
10   initialization of differential-algebraic systems in SIAM J. Sci. Statist. Comput., 9(2): 213-231, March 1988). In order to determine "column ranks", it is possible to use a method for determining "row ranks" when a transposed matrix is determined from that matrix of which the "column ranks" are to be
15   determined. The row ranks of the corresponding transposed matrix are then determined in order to determine the column ranks of the matrix.

This manner of determining the row ranks and column ranks for
20   the method according to the invention is not to be understood in a limiting way. Rather, it is also possible to use other methods to determine row ranks and column ranks if the remaining conditions for the presence of row ranks and column ranks are fulfilled.

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In the concluding step of the method according to the invention, for each row rank and for each column rank that had been determined in accordance with step 2, the numbers that are contained therein are output. In the case of the row

5   ranks, these numbers indicate the running numbers of the equations of the system of differential equations that are possibly affected by a structural problem. In the case of column ranks, the numbers contained therein and output as error information indicate the numbers of the components of

10   the solution vector $\underline{x}$ that are possibly affected by a structural problem.

The method according to the invention can be used even before the execution of numerical calculating steps or the building

15   of an analog computer to check the structure of the system of differential equations that is to be calculated for its consistency. If the method according to the invention had detected a system of differential equations as being inconsistent, it is possible to locate a large number of the

20   possible structural errors of the system of differential equations. This accelerates the location of errors. In addition, time-consuming simulation tests are avoided.

The method according to the invention can be applied for any

25   type of a simulation system for the numerical solution of systems of differential equations, and for the solution of

systems of differential equations by means of an analog computer.

In a particularly advantageous development of the invention,
5   before executing step 1 of the method according to the invention an equation significance list of length n is applied in which each equation of the system of equations is assigned an equation number and/or an item of equation text information. In exactly the same fashion, before executing
10   step 1 of the method according to the invention, a component significance list of length m is applied in which each component of the solution vector $\underline{x}$ is assigned a component number and/or an item of component text information. In this case, the equation text information or component text
15   information respectively stored in the significance list is advantageously selected such that this information acquires a significance in connection to the technical system to be simulated. Consequently, constituents of the simulated technical system and substructures of the technical system to
20   be simulated can be assigned equations of the system of differential equations and components of the solution vector $\underline{x}$ that facilitate an interpretation of the error information output with the aid of the method according to the invention.

25   In step 3 of the method according to the invention, for this purpose it is provided to output the equation number and/or

the item of equation text information in accordance with the

equation significance list instead of outputting the numbers

contained in each row rank. For the case in which a whole

number i is contained in the row rank, it is not the number i

5   that is output but rather the contents of the ith component of

the equation significance list. In exactly the same fashion,

in step 3 of the method according to the invention the

component number and/or the item of component text information

in accordance with the component significance list is/are

10   output instead of outputting the numbers contained in each

column rank. For the case in which the whole number j is

present in the column rank as a number, it is not the number j

that is output, but rather the contents of the jth component

of the component significance list.

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Owing to this refinement of the method according to the

invention, significance contents that refer directly to the

technical system to be simulated are output as error

information. This error information can be used to illustrate

20   with particular ease, systematic errors in the structure of

the system of differential equations for describing the

technical system, such that locating the errors is further

accelerated.

In the method according to the invention a preferably digital computer is used that has at least a memory, an arithmetic unit, an input device, and an output device.

5   The invention is also implemented in a computer program for providing error information relating to inconsistencies in a system of equations. The computer program is designed in this case such that after inputting of the system properties, the initial or boundary conditions and the influences on the

10   system, it is possible to execute an inventive method in accordance with one of the preceding claims. It is possible in this case to output results of a simulation, the solution vector or the solution vectors at different points in time. However, it is also possible for the computer program to

15   provide only information relating to inconsistencies in accordance with one of the preceding claims.

Because numerous defective program runs and/or simulation trials can be avoided, the computer program according to the

20   invention results in substantial improvements in run time by comparison with the known simulation programs and simulation methods.

Moreover, the invention relates to a data carrier with such a

25   computer program, and to a method in which such a computer program is downloaded from an electronic data network, such as

from the Internet onto a computer connected to the data network.

The computer system according to the invention is designed

5   such that it is possible to execute on it a method according to the invention for providing error information relating to inconsistencies in a system of equations.

Finally, the invention also relates to the use of a method

10   according to the invention and/or a computer system for providing error information relating to inconsistencies in a system of equations.

In the method according to the invention, the first step is to

15   set up the system or system of differential equations that describes the process, or other forms such as, for example, nonlinear systems of equations that have no differential equations. It is assumed here, in this case, that the person skilled in the art is conversant with the mode of procedure

20   required for this purpose. This is examined in detail in the specialist literature mentioned in the introduction to the description. There are also relevant computer programs for this purpose.

25   Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein, in general, as embodied in a method for providing error information relating to inconsistencies in a system of

5 differential equations, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

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The construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the

15 accompanying drawings.

Brief Description of the Drawings:

Fig. 1 is a set of functions and a parameter vector illustrating a first exemplary embodiment of the invention;

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Fig. 2 is a matrix and a corresponding set of transversal elements;

Fig. 3 is a set of functions and a parameter vector describing

25 a second exemplary system;

Fig. 4 is a matrix, a transversal, and column and row results;

Fig. 5 is an exemplary display of error results;

5   Fig. 6 is a schematic of an equivalent circuit;

Fig. 7 shows an equation significance list G and a component
significance list K; and

10   Fig. 8 is a resultant error list.

Description of the Preferred Embodiments:

The first exemplary embodiment in accordance with the
invention, relates to the simulation of a technical system

15   that can be described by the numerical solution of the system
of equations

$$\underline{f}\left(t, \underline{x}(t), \underline{\dot{x}}(t), \ldots, \underline{x}^{(k)}(t), \underline{p}\right) = \underline{0}$$

of the form

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$$f_1(x_1(t), x_2(t), x_3(t), \dot{x}_1(t), \dot{x}_2(t), \dot{x}_3(t), p_1, p_2, p_3) = 0,$$
$$f_2(x_1(t), x_2(t), x_3(t), \dot{x}_1(t), \dot{x}_2(t), \dot{x}_3(t), p_1, p_2, p_3) = 0,$$
$$f_3(x_1(t), x_2(t), x_3(t), \dot{x}_1(t), \dot{x}_2(t), \dot{x}_3(t), p_1, p_2, p_3) = 0,$$

having the functions f1, f2 and f3, and having the parameter
vector $\underline{p}$ in accordance with Fig. 1.

In order to predict the behavior of the system, the system of equations is solved numerically, that is to say values for the unknown vector $\underline{x}$(t) are calculated at one or more points in

5　time t. For this purpose, known methods of numerical solution are used which run as a computer program on a computer system.

According to the invention, steps for providing error information relating to inconsistencies in the system of

10　equations are executed before the actual solution of the system of equations.

The dependence matrix $\underline{\underline{A}}$ specified in Fig. 2 is determined in step 1 of the method according to the invention, all non-

15　vanishing elements of the dependence matrix $\underline{\underline{A}}$ being denoted in Fig. 2 by a star ("*").

The element $\underline{\underline{A}}$(1,1) picked out by way of example is set to an essentially arbitrary non-vanishing value "*", because the first element of $\underline{f}$, that is to say $f_1(t,\underline{x}(t),\underline{\dot{x}}(t),....,\underline{x}^{(k)}(t))$, is a

20　function of the first element of $\underline{x}$, that is to say of $\underline{x}_1$(t).

The element $\underline{\underline{A}}$(1,3) picked out by way of example is set to the value "0", because the third element of $\underline{f}$, that is to say

$\underline{f_j}(t,\underline{x}(t),\underline{\dot{x}}(t),...,\underline{x}^{(k)}(t))$, is independent of the first element of $\underline{x}$, that is to say of $\underline{x}_1(t)$ and of the derivatives of the first element of $\underline{x}$, that is to say $\underline{x}_1^{(s)}(t)$.

5   In step 2 of the method according to the invention, the first step is to determine the transversals T, specified in Fig. 2, of the dependence matrix $\underline{\underline{A}}$ with the aim of determining row ranks and column ranks of the dependence matrix $\underline{\underline{A}}$ specified in Fig. 2. Methods for determining transversals (of "maximum cardinality

10 bipartite matchings") are specified in I.S. Duff, "On algorithms for obtaining a maximum transversal", ACM Trans. Math. Software, 7(3):315-330, 1981, in E.L. Lawler, "Combinatorial Optimization: Networks and Matroids", Holt, Rinehart and Winston, 1976, in L. Lovasz and M.D. Plummer, "Matching Theory", North-Holland

15 Mathematics Studies 121. Annals of Discrete Mathematics, 29. North-Holland, 1986, or in C.C. Pantelides, "The consistent initialization of differential algebraic systems", SIAM J. Sci. Statist. Comput., 9(2):213-231, Mar. 1988.

20 The transversal T from Fig. 2 has 3 elements. Since n = m = 3, the dependence matrix $\underline{\underline{A}}$ from Fig. 2 has neither row ranks nor column ranks. No such row ranks of the dependence matrix $\underline{\underline{A}}$ are found by the method, specified in C.C. Pantelides "The consistent initialization of differential algebraic systems", for

25 calculating row ranks ("minimally structurally singular

subsets of equations"). The method specified there for

calculating row ranks also finds no such row rank of the

transpose of the dependence matrix $\underline{\underline{A}}$. It follows that there is

no column rank of the dependence matrix $\underline{\underline{A}}$. The set, determined

5   in step 2 of row ranks of the dependence matrix $\underline{\underline{A}}$ is empty.

The set, determined in step 2 of column ranks of the

dependence matrix $\underline{\underline{A}}$ is likewise empty. Consequently, no error

information is output in step 3 of the method according to the

invention.

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The system of equations specified at the beginning can be

solved with a higher probability without the occurrence of

errors. If the simulation is terminated nevertheless, or if it

supplies implausible solutions, or if it is entirely

15   impossible, then it is possible to exclude structural errors

in the description of the technical system or in the technical

system itself with a high degree of probability. This

substantially simplifies the location of errors.

20   The second exemplary embodiment in accordance with the

invention relates to the simulation of a further technical

system (not shown here), whose behavior can be described by

the numerical solution of the system of equations

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$$\underline{f}\left(t, \underline{x}(t), \underline{\dot{x}}(t), \dots, \underline{x}^{(k)}(t), \underline{p}\right) = \underline{0} \, ,$$

of the form

$$f_1(x_1(t), x_2(t), x_3(t), p_1, p_2, p_3) = 0,$$
$$f_2(x_1(t), x_2(t), x_3(t), p_1, p_2, p_3) = 0,$$
$$f_3(x_1(t), x_2(t), x_3(t), p_1, p_2, p_3) = 0,$$

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having the functions f1, f2 and f3 and having the parameter

vector $\underline{p}$ in accordance with Fig. 3.

It is aimed to solve the system of equations numerically in

10   order to predict the behavior of the system, that is to say

values are to be calculated for the unknown vector $\underline{x}$(t) at one

or more points in time t. Use is made for this purpose of

known methods of numerical solution (not illustrated here)

that run as a computer program on a computer system (not shown

15   here).

According to the invention, methods for providing error

information relating to inconsistencies in the system of

equations are executed for the actual solution of the system

20   of equations.

The dependence matrix $\underline{\underline{A}}$ specified in Fig. 4 is determined in

step 1 of the method according to the invention, all non-

vanishing elements of the dependence matrix $\underline{\underline{A}}$ being denoted by a star ("*") in Fig. 4.

5   The element $\underline{A}(1,1)$ picked out by way of example is set to an essentially arbitrary non-vanishing value "*", because the first row of $\underline{f}$, that is to say $\underline{f_1}\left(t,\underline{x}(t),\underline{\dot{x}}(t),...,\underline{x}^{(k)}(t)\right)$, is a function of the first element of $\underline{x}$, that is to say of $\underline{x}_1(t)$. The same holds for the elements $\underline{A}(1,2)$, $\underline{A}(1,3)$, $\underline{A}(2,3)$ and $\underline{A}(3,3)$.

10 The element $\underline{A}(3,1)$ picked out by way of example is set to the value "0", the third element of $\underline{f}$, that is to say $\underline{f_3}\left(t,\underline{x}(t),\underline{\dot{x}}(t),...,\underline{x}^{(k)}(t)\right)$, is independent of the first element of $\underline{x}$, that is to say of $\underline{x}_1(t)$ and of derivatives of the first element of $\underline{x}$, that is to say $\underline{x}_1^{(s)}(t)$. The same holds for the
15 elements $\underline{A}(2,1)$, $\underline{A}(3,2)$ and $\underline{A}(2,2)$.

In step 2 of the method according to the invention, the first step is to determine the transversals T, specified in Fig. 4, of the dependence matrix $\underline{\underline{A}}$ with the aim of determining row ranks
20 and column ranks of the dependence matrix $\underline{\underline{A}}$ specified in Fig. 4.

The row rank {2, 3} of the dependence matrix $\underline{\underline{A}}$ is found by the method for calculating row ranks ("minimally structured singular subsets of equations") specified in C. C. Pantelides
25 "The consistent initialization of differential algebraic

systems". The set Z of the row ranks, found in step 2, of the dependence matrix $\underline{\underline{A}}$ is specified in Fig. 4.

5   The row rank {1, 2} of the transpose of the dependence matrix $\underline{\underline{A}}$ is found by the method, specified in C.C. Pantelides, "The consistent initialization of differential-algebraic systems", for calculating row ranks applied to the transpose of the dependence matrix $\underline{\underline{A}}$. According to the invention, this row rank of the transpose of the dependence matrix $\underline{\underline{A}}$ is understood as

10   the column rank of the dependence matrix $\underline{\underline{A}}$. The set S of the column ranks, found in step 2, of the dependence matrix $\underline{\underline{A}}$ is specified in Fig. 4. The error information specified in Fig. 5 is output in step 3.

15   In accordance with the invention, there is not even an attempt to predict the behavior of the basic system using numerical means, because in this case errors will occur if a simulation is at all possible. However, the modeling of the system and the system itself need to be checked once again. This saves

20   valuable computing time on the computer system (not shown here). Error locating is substantially simplified by the knowledge of the error information output in step 3.

A third exemplary embodiment in accordance with the invention

25   relates to the technical system shown in Fig. 6, whose

behavior can be described by the numerical solution of the

system of equations

$$\underline{f}\left(t, \underline{x}(t), \underline{\dot{x}}(t), \ldots, \underline{x}^{(k)}(t), \underline{p}\right) = \underline{0} ,$$

5

of the form

$$f_1(x_1(t), x_2(t), x_3(t), p_1, p_2, p_3) = 0,$$
$$f_2(x_1(t), x_2(t), x_3(t), p_1, p_2, p_3) = 0,$$
$$f_3(x_1(t), x_2(t), x_3(t), p_1, p_2, p_3) = 0,$$

10   having the functions f1, f2 and f3 and having the parameter

vector $\underline{p}$ in accordance with Fig. 3.

It is aimed to solve the system of equations numerically in

order to predict the behavior of the system, that is to say

15   values are to be calculated for the unknown vector $\underline{x}$(t) at one

or more points in time t. Use is made for this purpose of

known methods of numerical solution that run as a computer

program on a computer system.

20   Error information relating to inconsistencies in the relevant

system of equations is provided in this case as follows

according to the invention.

The solutions of the relevant system of equations are quiescent states or "operating points" or "DC solutions" of the electric network specified in Fig. 6 and which comprises the following network elements ("components"):

5   □ a linear resistor with resistance value R between the nodes 1 and 2 of the network,

       □ a linear capacitor with a capacitance C1 between the nodes 1 and 0 of the network, and

       □ a linear capacitor with a capacitance C2 between the
10   nodes 2 and 0 of the network.

This results in the components of the parameter vector p, specified in Fig. 3, being according to the values C1, 1/R, C2.

15

The components x1(t), x2(t) and x3(t) of x(t) correspond to the following variables of the network specified in Fig. 6:

       □ x1(t) corresponds to the voltage between the nodes 1 and 0,

20   □ x2(t) corresponds to the voltage between the nodes 2 and 0, and

       □ x3(t) corresponds to the voltage between the nodes 1 and 2.

The first equation of the system of equations, that is to say, the equation

$$f1(x1(t),\ x2(t),\ x3(t),\ p1,\ p2,\ p3) = 0$$

5

is the Kirchhoff voltage equation for the mesh comprising all the three network elements of the network from Fig. 6.

The second equation of the system of equations, that is to

10   say, the equation

$$f2(x1(t),\ x2(t),\ x3(t),\ p1,\ p2,\ p3) = 0$$

is the Kirchhoff current equation for the nodes 1 of the

15   circuit in Fig. 6.

The third equation of the system of equations, that is to say, the equation

20           $$f3(x1(t),\ x2(t),\ x3(t),\ p1,\ p2,\ p3) = 0$$

is the Kirchhoff current equation for the nodes 2 of the circuit in Fig. 6.

The equation significance list G specified in Fig. 7 and the component significance list K specified in Fig. 7 are designed in accordance with the invention.

5   The set Z specified in Fig. 4, of the determined row ranks, and the set S, specified in Fig. 4 of the determined column ranks are determined as in the preceding exemplary embodiments.

10   The error information specified in Fig. 8 is output in step 3 of the method developed further in accordance with the invention, use being made of the equation significance list G and the component significance list K from Fig. 7.

15   It may be seen from the error information specified in Fig. 8 that the Kirchhoff current equations relating to the nodes 1 and 2 of the network from Fig. 6 are linearly dependent on one another, and that the two voltages between nodes 1 and 0 and between nodes 2 and 0 of the network from Fig. 6 for quiescent
20   states of this network cannot be uniquely determined.

In accordance with the invention, there is not even an attempt to predict the behavior of the basic system using numerical means, because in this case errors will occur if a simulation
25   is at all possible. However, the modeling of the system and the system itself need to be checked once again. This saves

valuable computing time on the computer system. Error locating

is substantially simplified by the knowledge of the error

information output in step 3.

5   The term "computer-readable medium" as used herein should be

understood in its broadest sense. That is, it includes, at the

least, any kind of computer memory such as floppy disks, hard

disks, CD-ROMs, flash ROMs, non-volatile and volatile ROM and

RAM, and memory cards, as well as carrier signals for distance

10   communication.